

*United States Marine Corps  
School of Advanced Warfighting  
Marine Corps University  
2076 South Street  
Marine Corps Combat Development Command  
Quantico, Virginia 22134-5068*

## **MASTER OF OPERATIONAL STUDIES**

***TITLE:*** SLIPPING THE LEASH: THE IMPACT OF FUEL CELL TECHNOLOGY ON THE  
MAGTF OF THE FUTURE

SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF OPERATIONAL STUDIES

**AUTHOR:** MAJOR MATTHEW S. COOK,  
UNITED STATES MARINE CORPS

**ACADEMIC YEAR 2005-2006**

---

Mentor:	_____	
Approved:	_____	
Date:	_____	

Mentor:	_____	
Approved:	_____	
Date:	_____	

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>2006</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2006 to 00-00-2006</b>	
4. TITLE AND SUBTITLE <b>Slipping the Leash: The Impact of Fuel Cell Technology on the MAGTF of the Future</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>United States Marine Corps,School of Advanced Warfighting, Marine Corps University,2076 South Street, Marine Corps Combat Development Command,Quantico,VA,22134-5068</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>18</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## Table of Contents

Disclaimer.....	2
Executive Summary.....	3
Introduction.....	4
The Current Paradigm.....	4
Fuel Cell Technology Defined.....	6
Maneuver.....	7
Command and Control.....	8
Force Protection.....	9
Logistics.....	11
Fires.....	12
Intelligence.....	13
Force Structure.....	14
Conclusion.....	15
End Notes.....	16
Bibliography.....	17

### ***DISCLAIMER***

THE OPINIONS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE INDIVIDUAL STUDENT AND DO NOT NECESSARILY REPRESENT THE VIEWS OF EITHER THE MARINE CORPS SCHOOL OF ADVANCED WARFIGHTING OR ANY OTHER GOVERNMENTAL AGENCY. REFERENCES TO THIS STUDY SHOULD INCLUDE THE FOREGOING STATEMENT.

QUOTATION FROM, ABSTRACTION FROM, OR REPRODUCTION OF ALL OR ANY PART OF THIS DOCUMENT IS PERMITTED PROVIDED PROPER ACKNOWLEDGMENT IS MADE.

## EXECUTIVE SUMMARY

**TITLE:** Slipping the Leash: The Impact of fuel cell technology on the MAGTF of the Future

**AUTHOR:** Major Matthew S. Cook, United States Marine Corps

**THESIS:** The application of fuel cell technologies in ground equipment will vastly improve the freedom of action of the MAGTF of the future and thereby increase its lethality.

**DISCUSSION:** Using its current inventory of fossil fuel burning ground equipment, the MAGTF's operational reach is significantly curtailed. It is forced to move and distribute large amounts of fuel in a format, liquid, that is difficult to transport. This challenge is exacerbated by the limited numbers of fuel storage, transportation, and distribution equipment it possesses. Through a controlled chemical process involving liquid hydrogen, fuel cells produce a tremendous amount of electrical energy. By harnessing this technology in its ground equipment, the MAGTF will realize profound benefits

**CONCLUSION:** If the Marine Corps vigorously pursues the development of fuel cell technologies for its ground equipment, it will exponentially improve the freedom of movement of the MAGTF. By looking at the impact fuel cell technology could have on the Marine Corps through the prism of the warfighting functions, it becomes clear that the second and third order effects are, in the main, extremely beneficial. Instead of the operational reach of the MAGTF being dictated by the internal combustion engine, it will be determined by the limitations of the human body.

## **Introduction**

Alternative fuel technologies, specifically fuel cell technologies, have the potential to profoundly enhance the capabilities of the Marine Air-Ground Task Force (MAGTF) now and in the future. This technology will end the MAGTF's dependence on fossil fuels, which will have a radical impact on how Marine units will be manned, equipped, and operate. The reach of Marine combat units will no longer be calculated by how far its equipment can travel on a tank of fuel, but rather by human physiology. This paper will illustrate the future impact of fuel cell technology on the Marine Expeditionary Force by using the warfighting functions as an analytic tool to explore the second and third order effects.

A generic Marine Expeditionary Force consisting of one Command Element, one Marine Division, one Marine Logistics Group, and one Marine Aviation Wing will serve to illustrate the benefits of fuel cell technology. The reader may also assume the Marine Expeditionary Force has sufficient capability to store its fuel requirements. Finally, this paper will assess the impact of applying fuel cell technology only on the MAGTF's ground equipment and not aviation assets. Due to the mature state of development, procurement, and fielding of the V-22 and Joint Strike Fighter (JSF), fuel cell technology will most likely affect the systems that replace them. Therefore, comparisons between a contemporary MAGTF and a fuel cell equipped MAGTF of equivalent size in the future will be predicated on the assumption that there will be no change in the respective aviation combat element's fossil fuel requirements for aircraft.

## **The Current Paradigm**

From the logistician's perspective, the two most difficult commodities to move around the battlefield are water and fuel. This is due primarily to the relatively limited capability of the

MAGTF to move these bulk liquids and the voracious appetite the Marine Expeditionary Force has for them. Aside from the canteen and five-gallon water can, the current inventory of Marine Corps equipment designed to distribute bulk water is limited to a 400-gallon trailer and a 900-gallon “pod”. The inventory of fuel distributing equipment is just as limited and consists of five-gallon fuel cans, 900-gallon fuel “pods” similar to the water pods, and the 5,000-gallon M970 Fuel trailer. Both the 900-gallon fuel and water pods are designed to be stacked on the bed of a medium or heavy tactical vehicle (Mk 23 or Logistics Vehicle System) and in conjunction with a 125 gallon-per-minute pump, dispense fuel or water directly into the using unit’s receptacle (fuel tank, water or fuel can, water trailer, etc.).

Unlike fuel however, indigenous water sources can be found within the MAGTF’s area of operations, which, coupled with the MAGTF’s robust water purification capability results in much shorter distribution requirements. In other words, the MAGTF can usually develop multiple water points within its area of operations, which allow it to minimize the distances that it has to move water to the units that require it. Bulk fuel, on the other hand, presents a much greater challenge. By its very nature, there is usually only one source within a theater of operation, which means that as the MAGTF maneuvers, units move away from that source of supply. While fuel is probably the most difficult class of supply to accurately calculate ahead of time, a generic planning factor is around 252,000-gallons per day for a Marine Expeditionary Force’s ground equipment<sup>1</sup>. To further complicate the matter, this requirement is not at one location but is instead usually spread throughout the Marine Expeditionary Force’s area of operations and can span hundreds of square miles. To move this 252,000-gallon requirement to units disbursed throughout its area of operations, the Marine Expeditionary Force has the ability to lift approximately 90,000-gallons at one time. Immediately the Marine Expeditionary Force

must deal with a 162,000-gallon shortfall, not to mention degradations in lift that accrue due to equipment maintenance, personnel issues, etc. This single shortfall is often the planning factor that places the greatest constraint on planners of Marine Expeditionary Force operations by determining how far the Marine Expeditionary Force can go before outrunning its fuel distribution capability.

### **Fuel Cell Technology defined**

Fuel cells may be the power generators for vehicles in the future. A fuel cell is a “continuous-feed electrochemical device of limited pulse-power capability. It produces electricity by oxidizing hydrogen. Fuel cells are categorized by the electrolyte that is contained within them and by their operating temperature. Air or oxygen acts as the oxidant, and hydrogen or hydrogen derived from a carbonaceous fuel is used.”<sup>2</sup> In other words, liquid hydrogen is passed through a series of filters while being exposed to oxygen in the air fed through the apparatus. When the hydrogen is exposed to the chemicals in the filters and the oxygen, a chemical reaction releases a tremendous amount of heat and energy that can be either stored in batteries for later use or used to power electric motors, which propel the vehicle. An interesting feature of this process is that instead of producing carbon monoxide and other pollutants as byproducts as in an internal combustion engine, the “exhaust” of fuel cells is purified water. The current form of fuel cells is the solid oxide fuel cell that has a service life of between ten and 20,000 hours depending on configuration.<sup>3</sup> Aside from the fuel cell itself, the other requirement required to capitalize on the advantages of fuel cell technology is the development of an electric drive system for ground vehicles. Electric drive systems can take two forms. The first is similar to vehicles currently in use in that an electric motor spins a drive shaft that, in turn, causes the axles of the vehicle to spin through a series of gears. The other form would call for an electric

motor to power each wheel. Regardless of which design is pursued, both, by virtue of the fact they are powered by electric motors and not internal combustion engines, operate with little noise. Development in this area is fairly mature as electric drive system prototypes for the M2 Bradley Fighting Vehicle, M113 Armored personnel carrier, and AAVP7 have been produced by the United Defense Corporation.<sup>4</sup> While there are numerous potential configurations that military fuel cell vehicles could take in the future, there are two that, if vigorously developed, could be operational by 2020.

One vision of fuel cell military vehicles that could be in use in 2020 is of a vehicles which the operators would put water into the fuel tanks.<sup>5</sup> In this configuration, the means to separate the hydrogen from the oxygen in water and compress it prior to use in the fuel cell would be designed into the vehicle itself. Another vision is of vehicles that would not have fuel tanks at all but instead have a “battery” which would have to be switched out periodically.<sup>6</sup> This battery would be a receptacle that would contain compressed, liquid hydrogen. The means to fill these receptacles could be provided with equipment that would be organic to the Marine Expeditionary Force or be prepared somewhere out of the theater of operations and shipped to the using unit in a manner similar to consumable batteries currently in use. The battery powered MAGTF of the future will be analyzed here, as it would present a greater challenge to distribute that the “water” configuration for fuel resupply.

## **Maneuver**

By utilizing ground equipment powered by fuel cells, the elements of the Marine Expeditionary Force would not have to move to a centrally located fuel point and wait for all of their vehicles to refuel before they could continue with their operations. Instead, the combat logistics elements of the Marine Expeditionary Force could replenish fuel in the same way

ammunition is currently re-supplied. For example, the supporting unit would arrive at a given unit's position and deliver the requisite number of fuel cell batteries to the unit's logistics unit and take custody of expended batteries. The logistics unit would then distribute the fresh batteries to the individual vehicles and collect the expended ones. The vehicle operators could then switch out vehicle batteries as required in the same way that a magazine of ammunition is replaced once it is expended. In short, the units that comprise the Marine Expeditionary Force could remain dispersed and not be required to periodically stop what they are doing and concentrate to deal with logistic issues. To place this impact in perspective, from D-Day to D+72 of Operation Iraqi Freedom (the "March Up"), I Marine Expeditionary Force's ground combat element and combat logistics element required slightly more than 12 million gallons of fuel<sup>7</sup>. This equates to 2,400 M970 fuel tanker trucks worth of lift and would require 80 hours or slightly less than four days to dispense with the M970's organic to the Marine Logistics Group. Of course, this does not take into account the amount of time it would take to shuttle the limited number of M970's back and forth from the fuel storage points to the supported maneuver elements. These constraints force the Marine Expeditionary Force to conduct periodic operational pauses and thereby disrupt momentum. Fuel cell powered vehicles such as those described previously would relieve the Marine Expeditionary Force of these burdens and enable momentum to be maintained, thus giving the commander more options.

## **Command and Control**

Because fuel cell powered ground equipment has the potential to enable maneuver elements to travel faster, farther, and on broader fronts, the MAGTF's ability to command and control will be challenged. Greater reliance may have to be placed on satellite communications as units are able to conduct distributed operations well beyond radio range. Further, such

distributed operations will enhance the importance of providing clear commander's intent and mission type orders.

Like the MAGTF Command Element, the impact the MAGTF's major subordinate elements' command and control requirements will be profound. While there will still be a necessity for detailed coordination between combat service support units and supported units in the future, the nature of it will change. Instead of designating a location along the supported unit's axis of advance or near its current position or forcing the unit to come to a fueling point and having to establish a fuel point in advance at one of these agreed upon locations, the combat service support unit will merely need to coordinate where the supported unit wants to receive its fuel cell batteries and in what amount. The CSS unit can then handle the request in the same manner that it would any other supply request. It will determine if the request is supportable, which of its subordinate elements has the requisite stocks, conduct the internal coordination to launch a mission to deliver the supplies, and then coordinate delivery and linkup with the supported unit. Combat service support units will no longer be required to track bulk fuel information or conduct internal coordination between bulk fuel storage sites and bulk fuel distribution organizations in order to conduct refueling operations in support of the Marine Expeditionary Force.

## **Force Protection**

There are numerous force protection benefits to using fuel cell equipped vehicles. The current doctrine for bulk fuel operations in support of a Marine Expeditionary Force calls for the CSS unit to establish several fuel storage sites known as "fuel farms" in the Marine Expeditionary Force's rear area. These fuel farms consist of large fuel bladders, hoses, and

pumps. They require large amounts of real estate not only for their physical configuration but also because of the explosive potential of the fuel itself. As a result of the physical requirements for storing bulk fuel, fuel farms present a lucrative target to enemy forces and a security challenge to the Marine Expeditionary Force.

When a ground unit requires fuel resupply, typically the supported unit will coordinate a location and a time with the supporting CSS unit to conduct the refueling. After the coordination, the CSS unit establishes a fuel dispensing point, which involves establishing a secure perimeter, a traffic flow plan, and staging areas. As CSS units typically have limited numbers of pumps with which to dispense fuel, the act of refueling individual vehicles can be a lengthy process. The unit to be refueled will arrive at the location and be placed in a staging area, individual vehicles will be called forward to the refueling points to be fueled, and then placed in another staging areas once they have completed fueling. If, for example, a tank company is being re-supplied using two LVS's each carrying two fuel pods and one pump, it will take approximately thirty minutes to refuel the company. This may not sound like much but one applies this metric to a Marine Division, it can add up to days.

With the fielding of fuel cell vehicles, it becomes unnecessary to establish fuel points in order to refuel vehicles. The CSS unit will merely have to deliver the required number of fuel cell batteries and the individual drivers of the maneuver unit can refuel as necessary without having to concentrate at one location and thereby present a target to the enemy. The potential for the sympathetic detonation of fuel farms due to surface-to-surface missiles is no longer a concern. And the requirement for large amounts of real estate in order to establish a fuel farm is removed. This adds up to a potential for more Marines staying in the fight.

One potential drawback from a force protection standpoint to using liquid hydrogen is its highly flammable nature. However, for each vision of fuel cell vehicles there are ways to mitigate this risk such as limiting the amount of liquid hydrogen being processed in the fuel cell at one time or through the design of the fuel container, or battery, itself.

## **Logistics**

Sustainment (with the exception of water) usually enters a theater of operations through a limited number of points. These points can take the form of ports, airfields, or both. As the MAGTF executes its mission, units tend to move farther and farther away from these points of entry. As a result, the MAGTF's combat logistics element is forced to periodically establish logistics nodes where stockpiles of several days worth of the various classes of supply are placed in an effort to shorten its lengthening lines of communication. By doing this, the CSSE is forced to prioritize transportation assets between moving supplies to establish these logistics nodes or distribute supplies from the logistics nodes to the maneuver units located throughout the MAGTF's area of operations. This challenge is exacerbated when the class of supply being moved is bulk fuel because of the limited numbers of fuel distributing assets. Conversely, transportation assets moving dry cargo such as the Mk 23 series and Mk 48 series (LVS) trucks are organic to the CSSE in large numbers and are usually underutilized.

Conversion to fuel cell vehicles will greatly enhance the Marine Corps ability to conduct sea-based logistics by doing away with the need to establish large fuel storage sites throughout the Marine Expeditionary Force's battlespace. Additionally, CSS units will not have to use their limited fuel distribution assets to echelon fuel forward to establish fuel farms in an attempt to shorten the logistic lines of communication while at the same time distributing fuel to the

MAGTF's maneuver units. Instead, they will be able to take advantage of their much greater numbers of dry cargo carrying vehicles to distribute fuel cell batteries to supported units and leverage the assault support assets in the MAGTF's Aviation Combat Element, which are much better suited to moving dry cargo than bulk liquid, to move fuel cell batteries between logistics nodes.

While conversion to fuel cells will not do away with the requirement to perform vehicle maintenance, the nature of the maintenance will change significantly. Because fuel cell vehicle engines have no moving parts like internal combustion engines, the maintenance requirement for fuel cell vehicles will be greatly reduced. The trend in new motor transport vehicles being fielded is to take a modular approach to maintenance whereby instead of repairing a component like a transmission or an alternator, mechanics replace the entire component. The implications of this might mean that instead of having to attempt to repair a malfunctioning fuel cell, a mechanic in the future will merely exchange it for a new one.

Fuel cell vehicles are expected to have little to no environmental impact. Regardless of which configuration of fuel cell technology the United States military ultimately selects, the only waste product produced by a fuel cell is purified water. No longer will the MAGTF have to spend inordinate amounts of time, manpower, and money cleaning up fuel spills. Therefore, converting to fuel cell powered vehicles will dramatically limit the environmental impact of a Marine Expeditionary Force.

## **Fires**

Under current doctrine, the Marine Logistics Group must establish strategically placed logistics nodes that take up large amounts of real estate throughout the Marine Expeditionary

Force's area of operations. Because these logistics nodes are essentially defensive positions, a significant amount of fire support planning must be done to support their defense. These nodes tend to be in rear areas, the principle fire support arm employed in their defense is close air support. Additionally, when the CSSE sends out subordinate elements to conduct resupply of maneuver units as described in the Force Protection section above, fire support, either artillery, close air support, or both, must be provided for in case the enemy attacks while the resupply is being conducted. While the conversion to fuel cell powered vehicles will not eliminate the need to plan for fire support in the establishment of logistics nodes or in support of combat service support operations, it will reduce the complexity of that planning by significantly limiting the time required to conduct the resupply and the manner in which it is conducted. While the CSSE will still need to establish logistics nodes but they will not need to be nearly as large. Also, because swapping fuel cell batteries is not nearly as involved as pumping fuel from a limited number of platforms, the amount of time required to resupply maneuver units will be reduced to a fraction of the time that it currently takes. Last but not least, the freedom of movement of artillery units, who are utterly reliant on their vehicles, will be greatly enhanced.

## **Intelligence**

Intelligence efforts in support of CSS operations often take two forms. The first form is proactive intelligence gathering. Currently, CSSE planners during the intelligence preparation of the battlespace portion of their planning, seek to find out such things in a potential area of operations as indigenous fuel sources, fuel storage facilities, fuel distribution assets, and locations suitable for establishing logistics nodes. These considerations often drive how the CSSE task organizes itself and physically lays itself down in a given area of operations to best support the MAGTF.

The other form intelligence takes in support of the CSSE is counterintelligence. Counterintelligence seeks to deny the enemy information about us, which he may use to disrupt our operations. For the CSS planning, counterintelligence encompasses information on the size and location of our logistics nodes, targeting information, and the methods we use to conduct resupply.

The application of fuel cell technology will eliminate the need to collect information on bulk fuel storage and distribution capabilities in a proposed area of operations. Also, because logistics installations will be much smaller (or even not established ashore) as a result of not having large fuel farms, it will be more difficult for potential adversaries to collect information or conduct targeting. In other words, the combat logistics element will still require intelligence support, but the nature of that support will be changed.

## **Force Structure**

In addition to the benefits described in the preceding sections, there are some further benefits which do not neatly fit into a given warfighting function. Conversion to fuel cell vehicles would realize a force structure savings for the Marine Corps in the area of bulk fuel military occupational specialties. The generic Marine Expeditionary Force has one Bulk Fuel Company organic to the Marine Logistic Group. This company is composed of six officers and 259 Marines. Assuming that each of these companies could each be reduced to platoon size to continue to support the Marine Aircraft Wings, over 500 Marines (not including the Bulk Fuel Companies in the Reserves) would be freed up to be used in other critical MOS's.

Force structure savings can be realized in the area of motor transport maintenance military occupational specialties also as a result of the reduced maintenance requirement for fuel

cell vehicles. This number is harder to calculate because there may be some as yet undetermined maintenance requirement for fuel cell powered vehicles. For example, a new military occupational specialty may have to be created to produce the liquid hydrogen receptacles if it is determined that this capability should be organic to the Marine Expeditionary Force.

## **Conclusion**

If the Marine Corps vigorously pursues the development of fuel cell technologies for its ground equipment, it will exponentially improve the freedom of movement of the MAGTF. By looking at the impact fuel cell technology could have on the Marine Corps through the prism of the warfighting functions, it becomes clear that the second and third order effects are, in the main, extremely beneficial. Instead of the operational reach of the MAGTF being dictated by the internal combustion engine, it will be determined by the limitations of the human body. However, with the research in human performance enhancement being pursued by the Department of Defense, there may be no way of determining the MAGTF's operational reach.

## Notes

1. United States Marine Corps, Marine Corps Warfighting Publication 4-25.5, Bulk Fuel Operations (Quantico: Doctrine Branch),
2. Defense Technical Information Center (DTIC), Militarily Critical Technologies List, Section 7 (Washington, D.C.: 2005), 7-22.
3. DTIC, 7-41.
4. DTIC, 7-18.
5. Dr. Jeffery Tew, phone interview by Major M. S. Cook, 14 September 2005.
6. James Gough (Fleet Manager, I&L, HQMC), phone interview by Major M. S. Cook, 22 November 2005.
7. Chief Warrant Officer-2 Kurt J. Westrup phone interview by Major M. S. Cook, 27 February 2006.

## Bibliography

United States Marine Corps, Marine Corps Warfighting Publication 4-25.5, Bulk Fuel Operations (Quantico: Doctrine Branch),

Marine Air-Ground Task Force Staff Training Program, MSTP Pamphlet 5-0.3, MAGTF Planner's Reference Manual (Quantico: MSTP), 2001.

Defense Technical Information Center (DTIC), Militarily Critical Technologies List, Section 7 (Washington, D.C.: 2005), 7-22.

Dr. Jeffery Tew, phone interview by Major M. S. Cook, 14 September 2005.

James Gough (Fleet Manager, I&L, HQMC), phone interview by Major M. S. Cook, 22 November 2005.

---